Statistical Methodology to Optimize Testing for Small Arms

DISTRIBUTION STATEMENT A.
Approved For Public Release.

AORS, NOV 2014

Kristina Bevec
410.278.4720
Kristina.m.bevecmohl.civ@mail.mil

Agenda

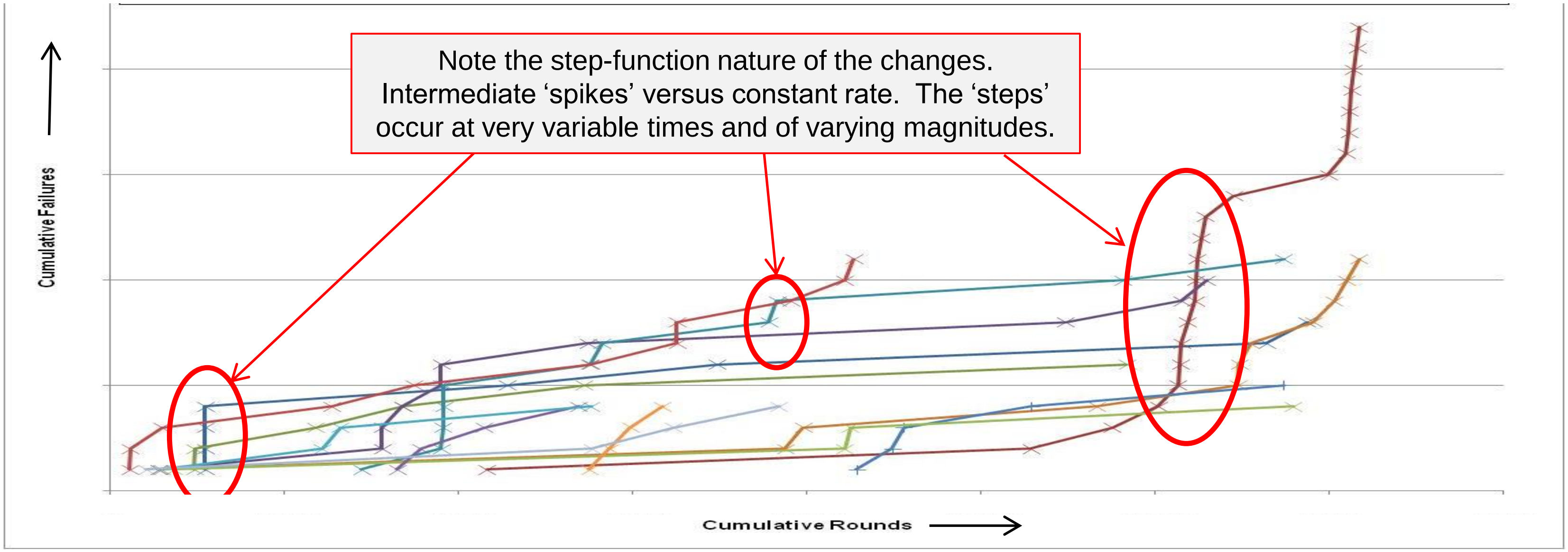
- Background
- DLR Model
- Instantaneous MRBF Results
- Comparison with Constant Reliability Assumption
- Comparing Factors
- Example Application
- Benefits of New Method

Background (1/2)

- AMSAA provided a comprehensive review of small-arms reliability T&E in 2013 including the
  - Confirmation of reliability test results from 2006 to 2012,
  - Sufficiency of reliability T&E methods,
  - And the appropriateness of current Individual Carbine reliability requirement.
- Test data prior to 2013 shows:
  - The failure probability may increase over the life of the weapon
  - The probability is not constant (e.g. distinct tread–riser-tread step functions)
  - Variability in amount of change across weapons (e.g. total amount of change)
  - Variability in when significant changes occur (e.g. when/how often ‘steps’ occur)

Significant weapon-to-weapon variability existed in previous small arms.

Background (2/2)



- ❑ Numerous findings from review included
  - Significant weapon-to-weapon variability;
  - Future testing should be constructed using DoE principles;
  - Future reliability requirements should include a system-level metric (weapon, ammo, magazine,…);
  - Continue engineering efforts to understand & resolve current component interfacing issues.

A more rigorous statistical model needed to assess small-arms reliability

DLR Model (1/2)

- Inputs include weapons and their failures from past and present test events
- Include factors of interest within dynamic model framework
  - Allows for comparisons between tests, weapons, ammo, magazines, etc.
- Use dynamic Bayesian approach to account for changing reliability over time
  - Provides updated reliability assessment by round
  - Computationally efficient
  - Binomial data with Non-informative Beta prior -> data-driven

Increase the amount of test data and factors may increase the certainty of their overall influence on system reliability

DLR Model (2/2)

- Expectation-Maximization algorithm used to estimate model evolution parameters
  - Determines the β parameters that maximize the log likelihood of the observed data, where

$$\vec{\beta} = \{\beta_0, \beta_1, ..., \beta_N\}$$

$$\beta_i = G\beta_{i-1} + W$$

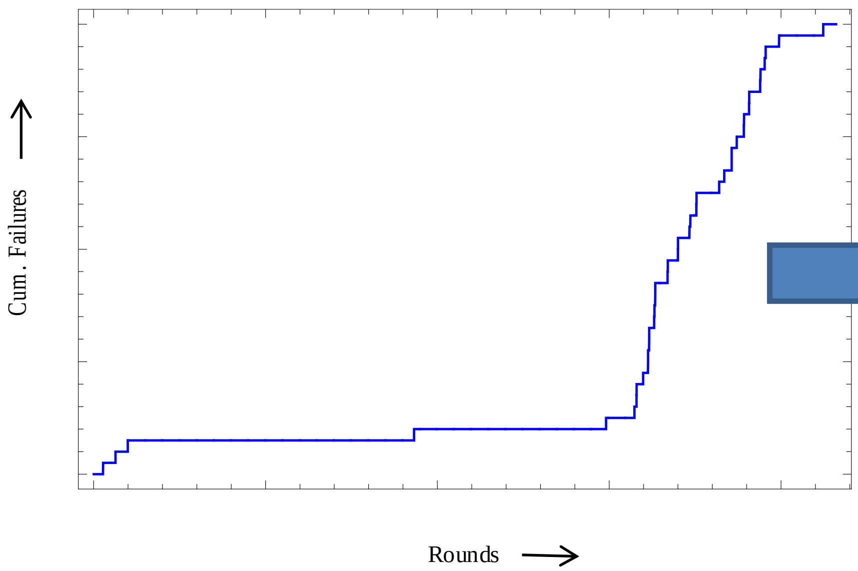
- Uses logistic regression form with probability of failure on i^{th} round given by:

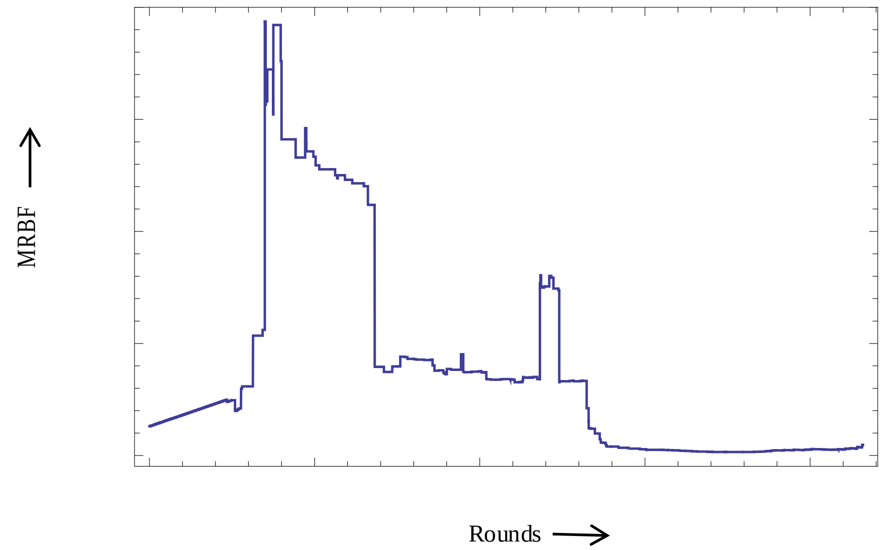
$$\log \frac{p_i}{1 - p_i} = \beta_0 + \beta_1 x_{i,1} + \beta_2 x_{i,2} + \ldots + \beta_N x_{i,N}$$

Indicator variables for factors such as weapon, ammo, new/rebuilt, etc.

Instantaneous MRBF Results

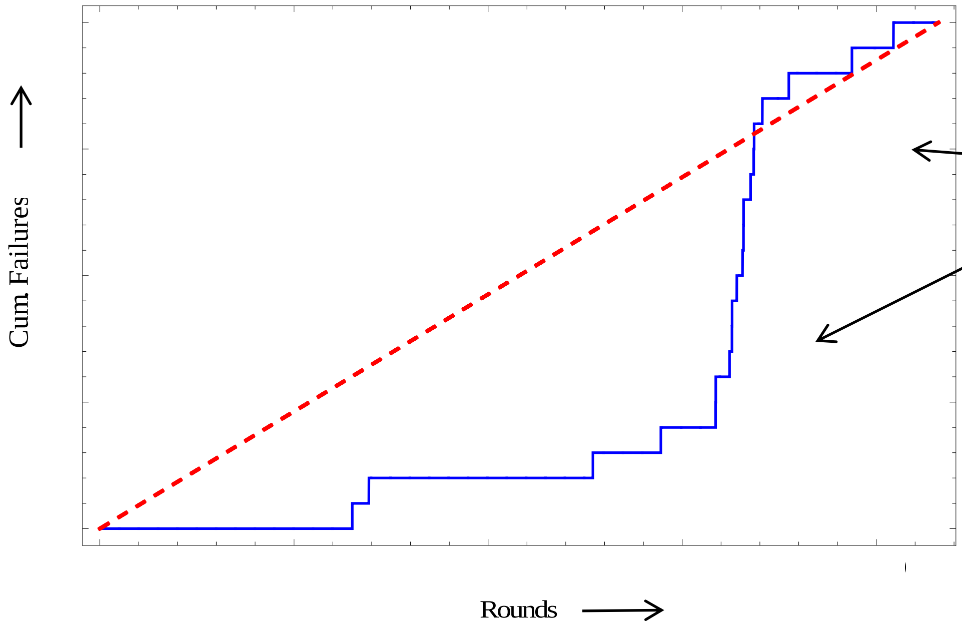
- Plot instantaneous MRBF by round
  - Reflects dynamic nature of failures as they occur throughout the test
  - Also impacted by information from other weapons within test





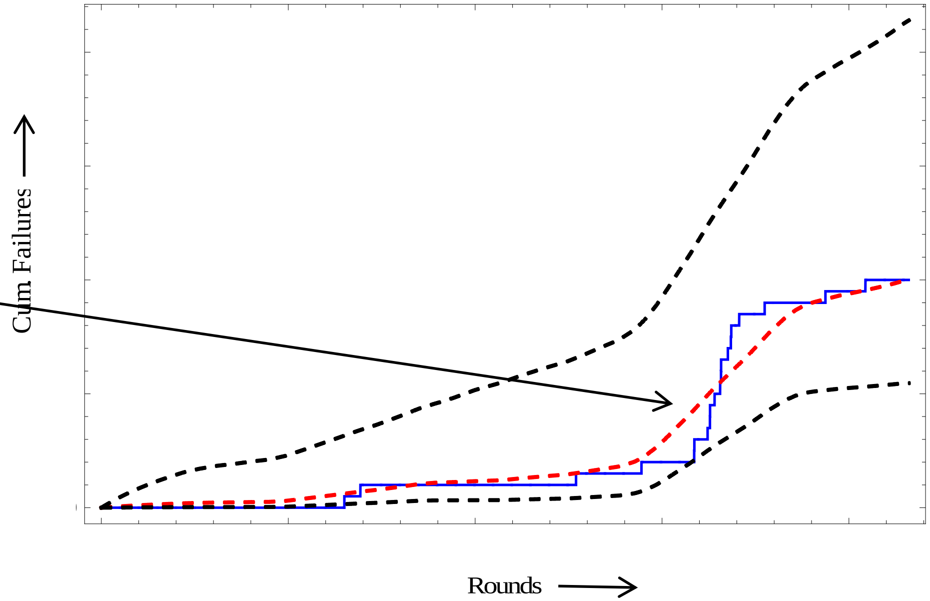
Proposed method provides more accurate reliability estimates

Comparison with Constant Reliability Assumption



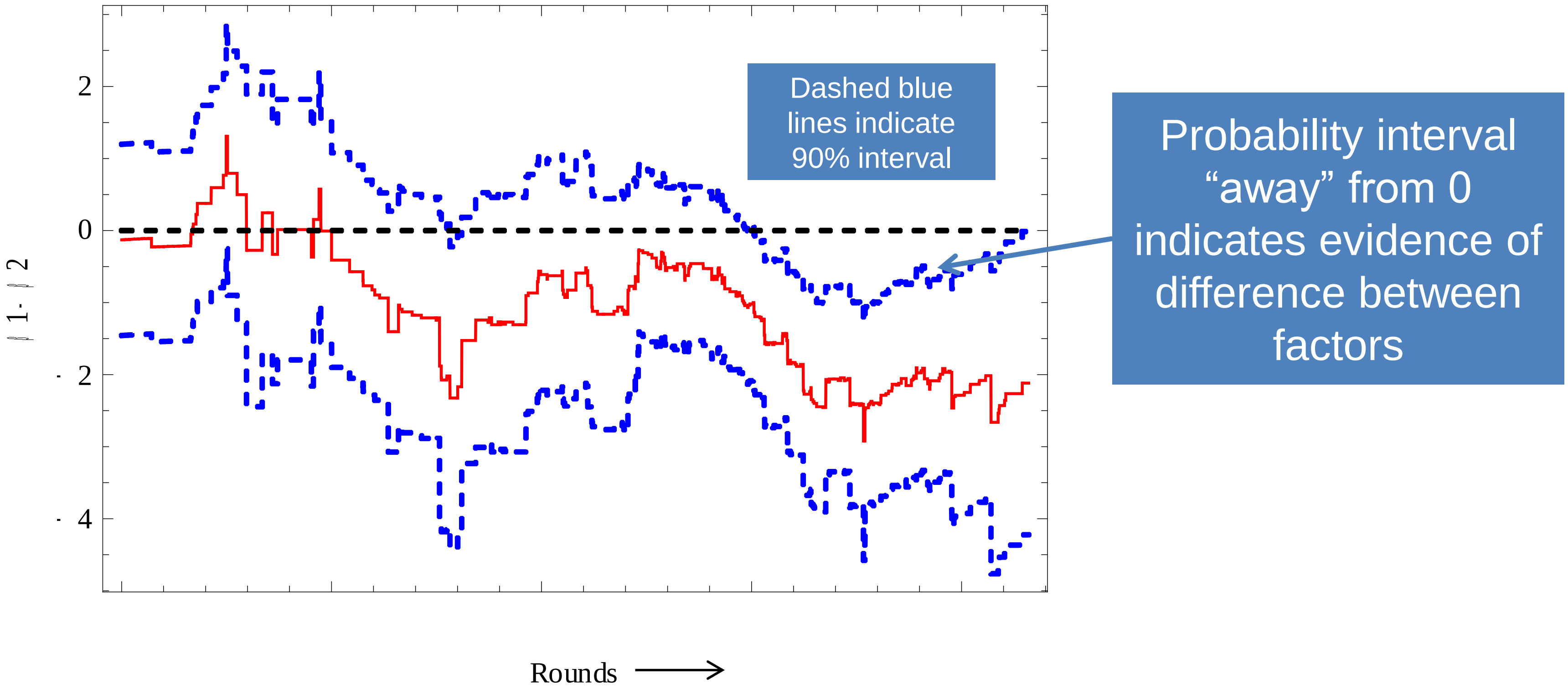
Rapidly changing reliability violates assumption of constant reliability

Proposed method easily handles changes over time; also includes interval estimates



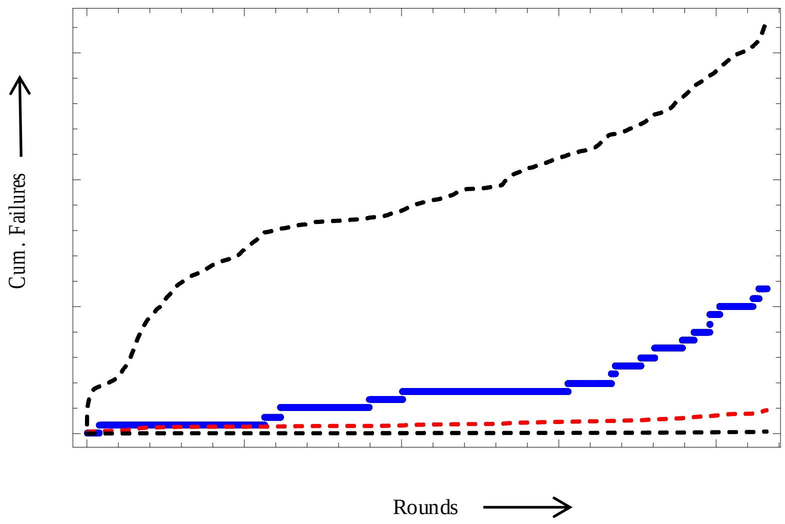
Comparing Two Factors

- Use model parameters to understand differences between factors within model
  - Parameters are approximately jointly Normal, which allows for interval estimates

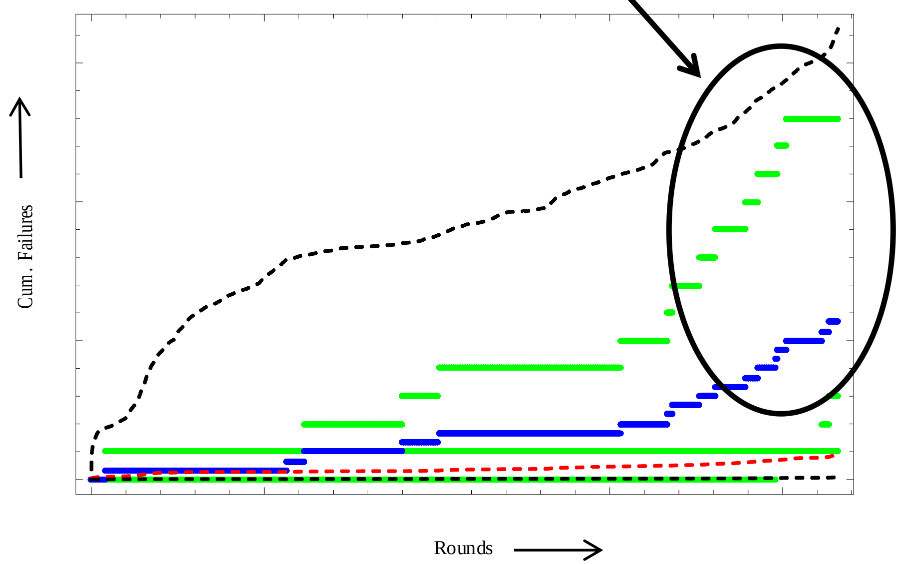


Examining Model Fit

- Model fit using average results can be misleading
- Averages can be skewed by small samples with variation between weapons



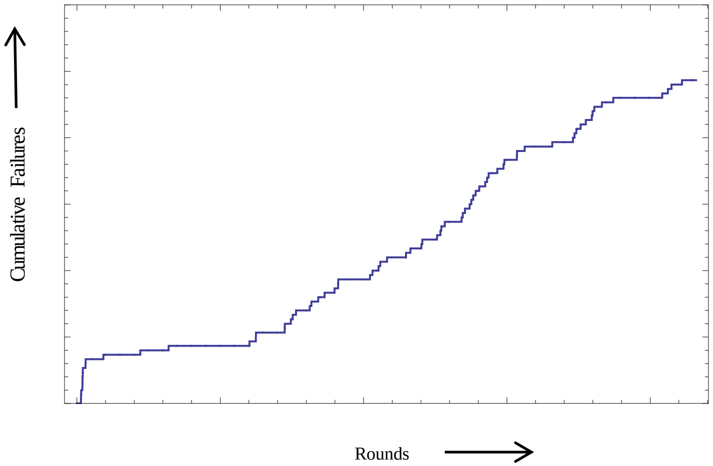
Average value skewed by higher number of failures on 3rd weapon



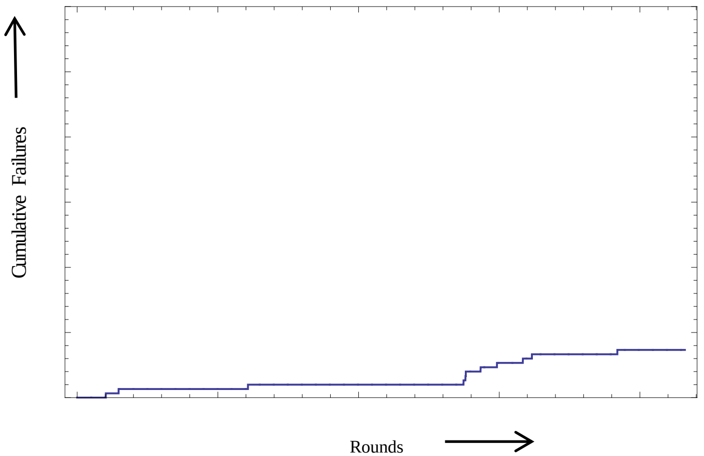
Model performs as expected; Provides reasonable description of observed data

Example Application

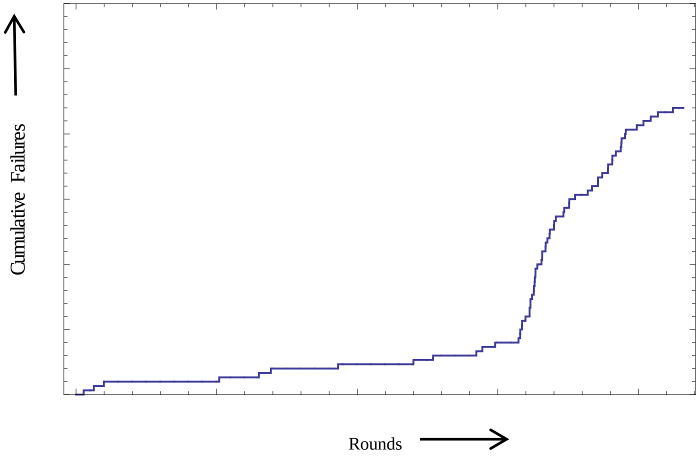
Weapon 1/Ammo 1



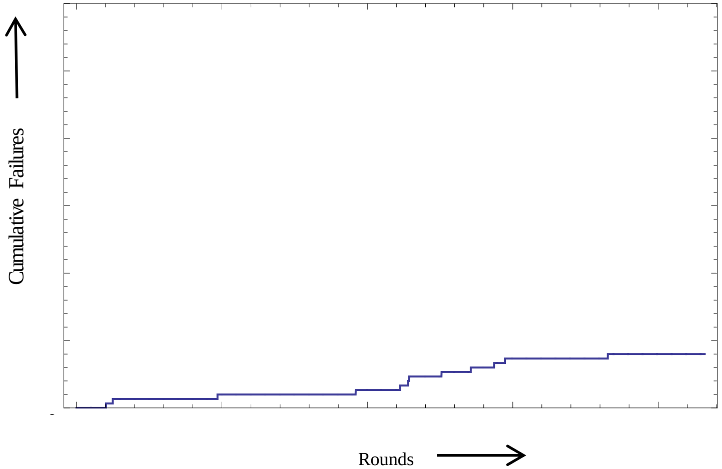
Weapon 1/Ammo 2



Weapon 2/Ammo 1



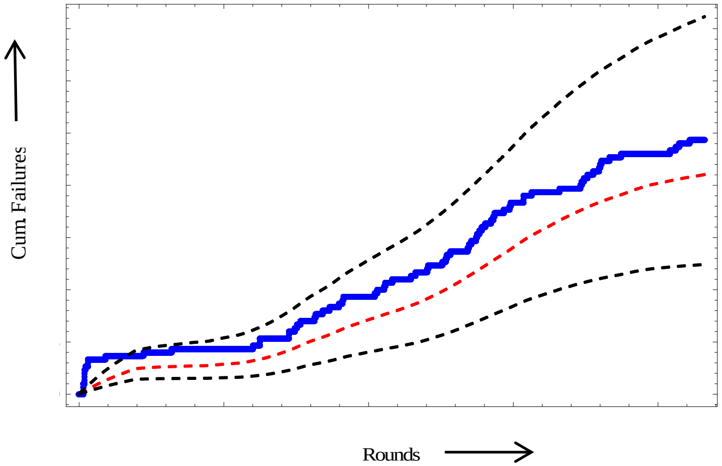
Weapon 2/Ammo 2



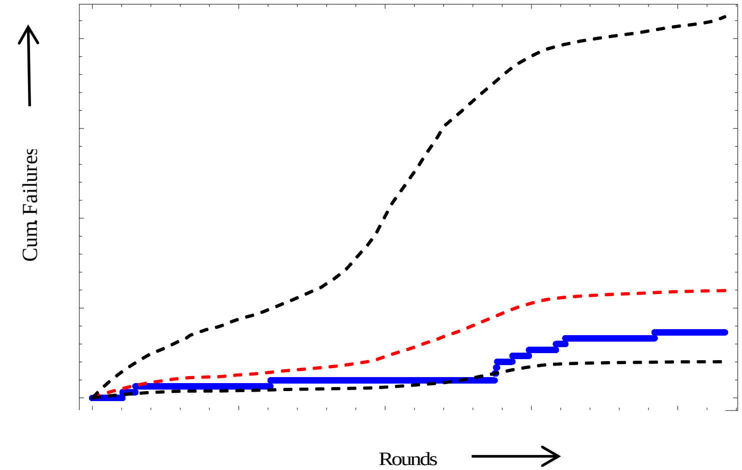
2 Weapons, 2 Ammunition types x Total rounds per each case

Average Results for Weapon/Ammo Factors

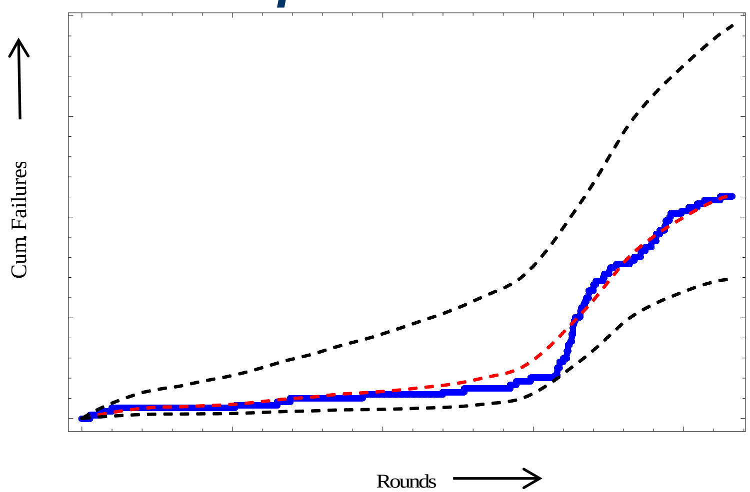
Weapon 1/Ammo 1



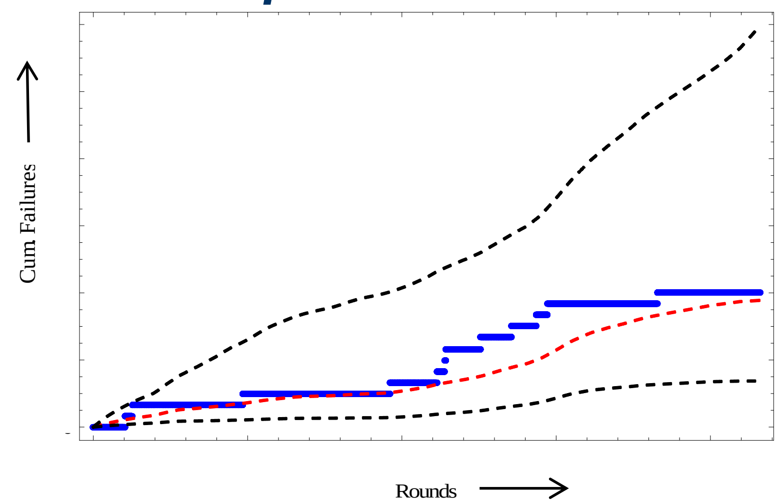
Weapon 1/Ammo 2



Weapon 2/Ammo1



Weapon 2/Ammo 2



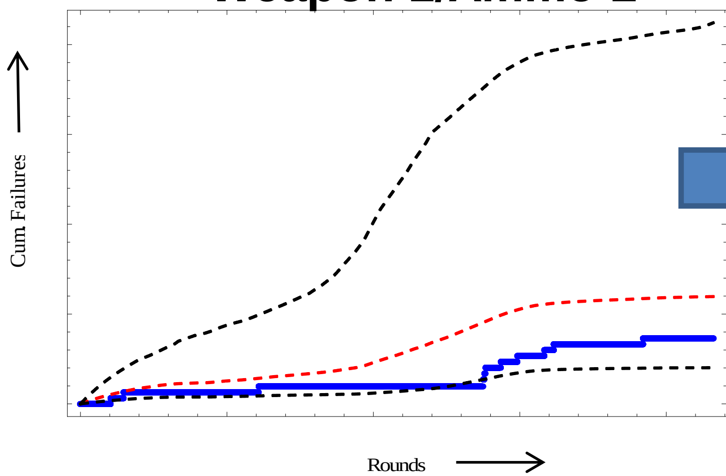
Model fit can be improved by considering additional factors

--- Dashed black lines indicate 90% interval

Including Individual Gun as Factor

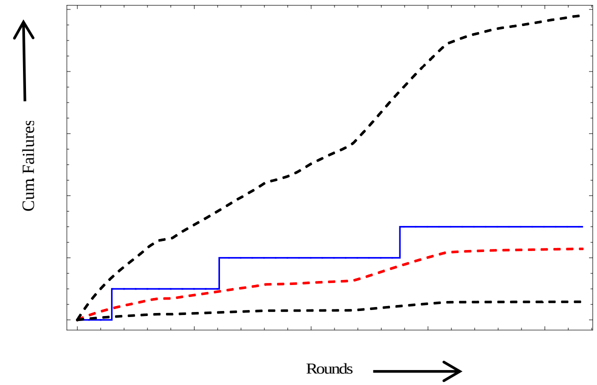
AMSAA
Excellence in Analysis

Average Result: Weapon 1/Ammo 2

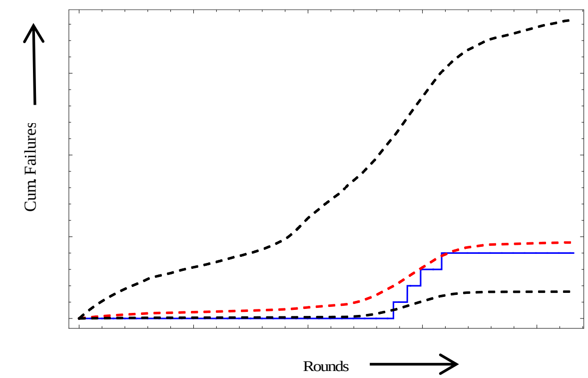


Individual gun can be easily added to improve fit; Still allows for comparisons between Weapon 1/Weapon 2, etc.

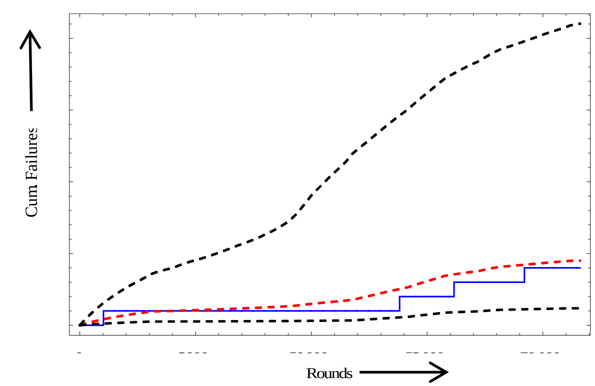
Gun 1



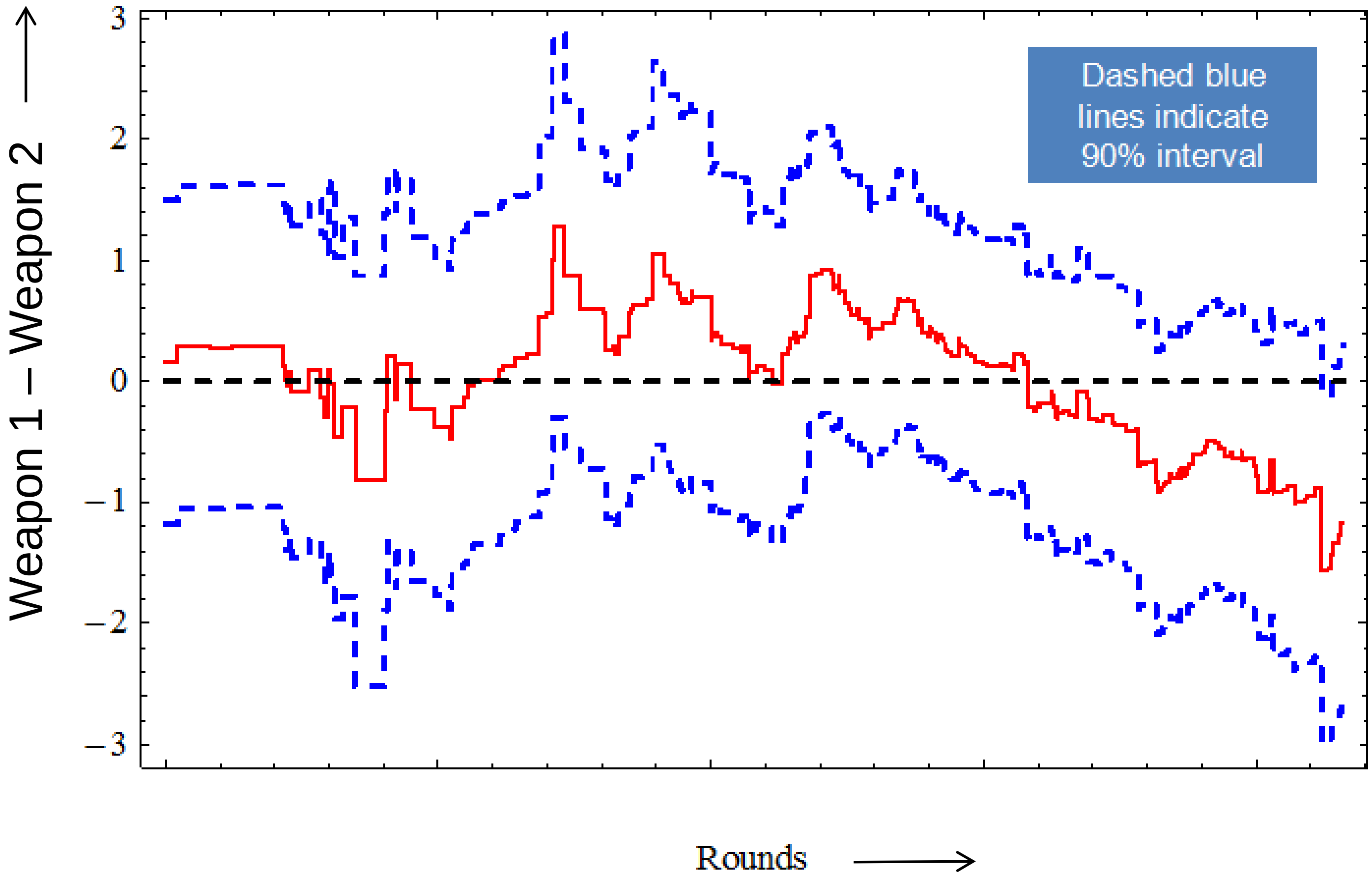
Gun 2



Gun 3

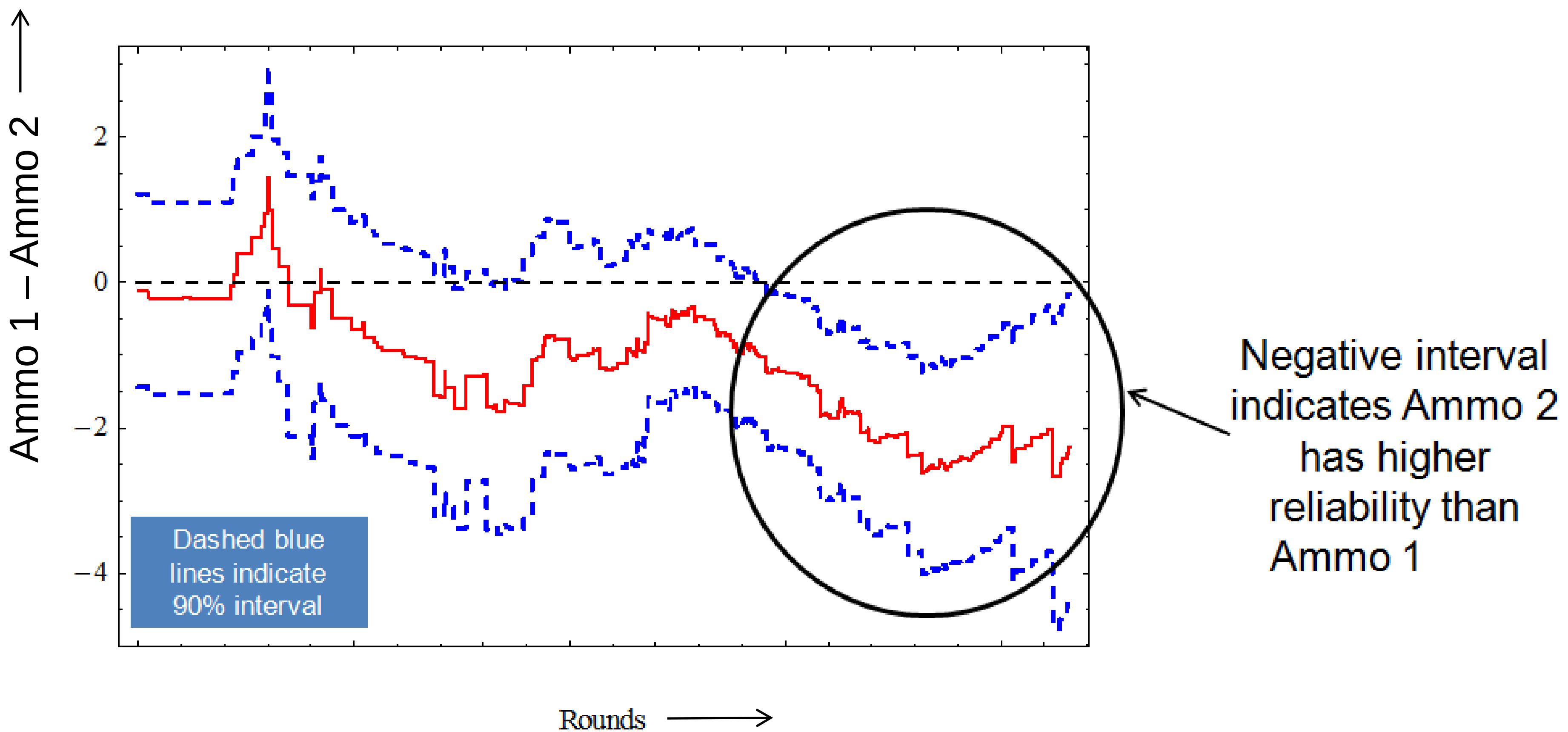


Comparison Results: Weapon 1 vs. Weapon 2



No evidence of significant difference between weapons

Comparison Results: Ammo1 vs. Ammo 2



Evidence of minor differences as few rounds fired

Significant differences exist as more rounds fired

Benefits of New Method

- Handles dynamic trends in reliability
- Includes interval estimates
- Allows for straightforward comparisons between factors (e.g. weapon, ammo, new vs. rebuilt, etc.)
  - Determines the amount of influence a factor has on overall weapon reliability
  - Results in a more rigorously designed test, which could potentially reduce cost during the weapon's developmental and operational testing
- Can pool data from past and previous tests to update assessments over time
- DLR approach can be used to appropriately size future tests
  - Number of weapons and ammunition needed to achieve reliability estimate